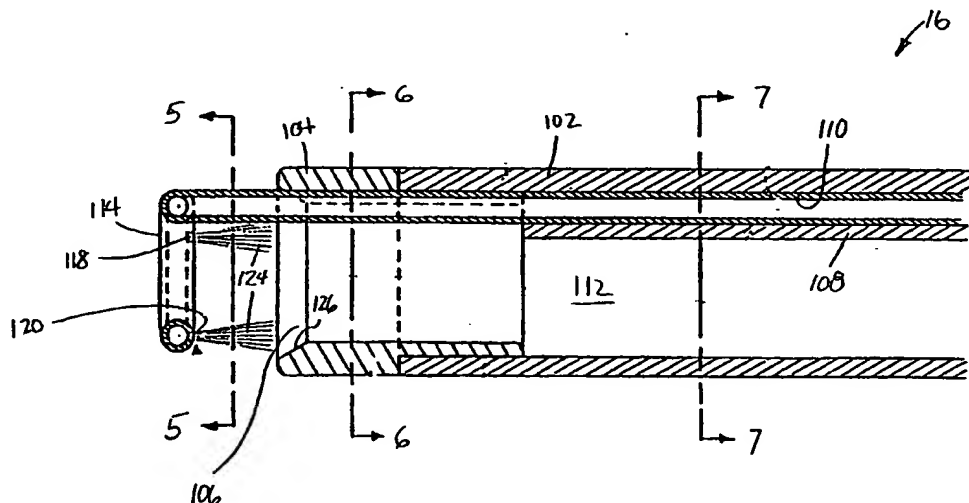




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(54) Title: THROMBECTOMY AND TISSUE REMOVAL METHOD AND DEVICE**(57) Abstract**

A method and apparatus for removing a thrombus or other tissue deposit from the cardiovascular system. A catheter (16) is inserted percutaneously into the patient at a convenient location either directly or over a previously positioned guide wire or inside a guide catheter. The distal end of the catheter is advanced under fluoroscopy to the site of the thrombus or tissue deposit. A flexible metal or high-pressure plastic tube (110) conveys an extremely high-pressure stream (124) of sterile saline or other physiologic solution to at least one jet (118, 120) at the distal end of the catheter. At least one jet (120, 118) is directed at the opening of a large exhaust lumen (112) or other target. The jet(s) is responsible for providing a localized negative pressure which entrains tissue into the jet from breakup of the debris. This jet(s) can also provide stagnation pressure in the exhaust lumen which drives the tissue or thrombotic debris out of the exhaust lumen.

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THROMBECTOMY AND TISSUE REMOVAL METHOD AND DEVICE

CROSS REFERENCE TO CO-PENDING APPLICATIONS

5 This patent application is a continuation-in-part of U.S. Serial No. 07/563,313, filed August 6, 1990, entitled "Thrombectomy Method and Device," to the same assignee as the present patent application.

BACKGROUND OF THE INVENTION

10 1. Field of the Invention - The present invention relates generally to medical devices and procedures, and more particularly, relates to medical devices and procedures for removing thrombus or other tissue deposits from the cardiovascular system, natural or synthetic tubule or cavity found in the human body.

15 2. Description of the Prior Art - Procedures and apparatus have been developed for ease in removing various tissue. U.S. Patent No. 4,790,813 issued to Kensey and U.S. Patent No. 4,842,579 issued to Shiber describe techniques for the removal of plaque deposited in arteries by mechanical ablation using rotating cutting
20 surfaces. These relatively traumatic approaches are directed to the treatment and removal of very hard substances.

25 In current medical procedures, thrombus and other tissue are often removed using a catheter such as is described in U.S. Patent No. 4,328,811 issued to Fogarty. In this system, a surgical cutdown is performed to access the vessel and allow catheter entry and advancement to a point beyond the deposit. The balloon is inflated and the catheter is withdrawn pulling the tissue along with
30 it.

Pressurized fluids have also been used in the past to flush undesirable substances from body cavities. U.S. Patent No. 1,902,418 describes such a system for domesticated animals. The more modern approaches tend to

use vacuum rather than gravity as the primary means for removal of the deposits or tissue and relatively low fluid pressures to cut into and fragment the substances to be removed.

5 U.S. Patent No. 3,930,505 issued to Wallach describes a surgical apparatus for the removal of tissue from the eye of a patient. As with similar systems, Wallach uses a relatively low pressure jet of water (i.e. 15 to 3500 psi) to disintegrate the tissue, and a
10 suction pump to perform the actual removal.

A similar approach applied to the cardiovascular system is discussed in U.S. Patent No. 4,690,672 issued to Veltrup. Veltrup also provides a much lower pressure jet of water (i.e. less than 450 psi) to fragment
15 deposits. As with Wallach, Veltrup uses a vacuum pump for evacuation of the fragments. The distal end of the Veltrup catheter is repositionable and requires manual entrapment of the deposits, or else the catheter jet must be moved into contact with the deposit in order to
20 accomplish tissue fragmentation. The vacuum applied by the suction duct holds the tissue at its opening while a jet of water breaks up a solid structure at its mouth. This device is basically a suction tube which requires a vacuum to operate, but contains a distal jet aimed at the
25 distal opening in order to reduce blockage of the opening.

SUMMARY OF THE INVENTION

The present invention achieves the removal of unwanted tissue by utilizing high-pressure fluid jets at
30 the distal tip of a catheter to draw the tissue towards the catheter and cut or emulsify the tissue; the resulting slurry of tissue and liquid can then be removed through an exhaust lumen of the catheter, and the fluid jet(s) can provide energy to drive this exhaust. The

present invention overcomes the disadvantages of the prior art systems by operating at higher pressures than those envisioned by Veltrup, thereby providing for entrainment of the thrombus or tissue into the fluid jet(s). In addition, the higher pressures produces a force which can be used to drive the fragmented tissue out of the catheter without using vacuum. The catheter can draw nearby thrombus or tissue towards the fluid jet(s), which then fragments it without requiring that the catheter be moved into direct contact or juxtaposition with the tissue. The high energy of the jet impinging on the opening to the evacuation lumen eliminates the need for a vacuum pump, as the fragmented debris is removed by the evacuation lumen as it is driven out with a driving force above atmospheric pressures.

According to the present invention, energy is added to the system via an extremely high pressure stream(s) of liquid, solution, suspension, or other fluid, such as saline solution, which is delivered to the distal end of the catheter via a high pressure tubing, which directs jet(s) of high velocity fluid at the opening of an exhaust lumen. This stream serves to dislodge thrombus deposits, entrain them into the jet, emulsify them, and drive them out of an exhaust lumen. Tissue or debris such as thrombus particles are attracted to the jet(s) due to the localized high velocity and resultant localized low pressure. Recirculation patterns and fluid entrainment bring the thrombus continually into close proximity of the jet(s). Once emulsified by the jet, the tissue can be removed through the exhaust lumen by flow generated as a result of stagnation pressure which is induced at the mouth of the exhaust lumen by conversion of kinetic energy to potential energy (i.e., pressure) of at least one fluid jet directed at and impinging on the

lumen mouth. The pressure in the high pressure fluid tubing must be great enough to generate a high localized velocity, and hence, a low localized pressure necessary to entrain the surrounding thrombus or tissue. A high enough pressure to generate substantial stagnation pressure at the opening to the exhaust lumen is necessary to drive the exhaust flow. A pressure of at least 500 psi is needed for the high pressure fluid at the tip, and pressures of over 1000 psi will provide even better entrainment and stagnation pressures. The stagnation pressure formed at the mouth of the exhaust lumen serves to drive the fragmented thrombus or tissue out of the exhaust lumen. This pressure can typically be greater than one atmosphere, and therefore, provides a greater driving force for exhaust than can be accomplished by using a vacuum pump. Additional jets of lower energy may be directed radially outward to aid in removal of thrombus or tissue from the vessel wall, and provide a recirculation pattern which can bring fragmented tissue into contact with the jet(s) impinging on the exhaust lumen opening.

The procedure is practiced by percutaneously or intraoperatively entering the vascular system, tubule, or other cavity of the patient at a convenient location with a cannula. The catheter may be inserted either directly or over a previously positioned guide wire and advanced under fluoroscopy, angioscopy or ultrasound device to the site of the vascular occlusion, obstruction or tissue deposit. The exhaust lumen can permit the passage of an angioplasty dilation catheter, guidewire, angioscope, or intravascular ultrasound catheter for intravascular viewing. The lesion site may contain an aggregation of blood factors and cells, thrombus deposit, or other tissues which are normally identified by angiography or

other diagnostic procedure. One or more balloons may be inflated to stabilize the distal end of the catheter and provide a degree of isolation of the area to be treated. An isolation balloon located proximal to the high pressure fluid jets can prohibit fragmented tissues from migrating proximally around the outside of the catheter shaft and immobilizing into a side branch of a blood vessel. An isolation balloon distal to the high pressure fluid jets can prohibit immobilization distally. This may be of greater importance if immobilization of fragmented debris may generate unfavorable clinical sequelae. Thrombolytic drugs such as streptokinase, urokinase, or tPA, and other drugs may be delivered through the catheter along with the saline or separately to adjunctively aid in the treatment of the lesion. A balloon may also be located at the distal end of the catheter to provide the capability of dilation of the vessel, tubule, or cavity either prior to or following the thrombus or tissue ablation and removal.

The catheter described herein is a part of a system in the first embodiment (FIG. 1) which includes a high pressure fluid supply, the fluid being either sterile saline or other suitable physiological solution compatible with the site of catheter operation within the body. The high pressure of the fluid can be generated with a positive displacement pump, such as a piston pump, which can be made to operate with either pulsatile flow or with steady flow. The catheter and the piston pump can be sterile. A nonsterile motor and motor control system can be used to power the piston pump. Sterile saline and physiological solution available to radiological, cardiological and operative sites can be used as a source of fluid from the high pressure positive displacement pump. The high pressure fluid flow from the

pump is supplied via a high pressure tube to the distal end of the catheter where at least one jet of fluid is directed toward the opening of an exhaust lumen. A metering device may also be a part of the system which includes the catheter and the high pressure fluid supply. A metering system can be utilized at the proximal end of the exhaust lumen to regulate the flow rate of the fragmented thrombus or tissue out of the catheter. The flow of fragmented tissue out of exhaust lumen can exceed the flow of high pressure fluid from the jet(s) which impinge on its distal opening. As a result, a metering device can be used to reduce the volumetric outflow rate of fragmented tissue such that it is equal to, or in balance with, the volumetric rate of high pressure fluid being supplied to the distal tip. This balance of flow would then insure that the fluid volumes within a blood vessel, tubule or body cavity is not being significantly altered during the thrombectomy or tissue removal procedure. The outlet flow rate of the tissue fragments can also be adjusted such that it is either greater than or less than the high pressure fluid supply rate, in order to either drain or expand the fluid volume within the vessel or cavity. The metering device can be any device with means of measuring the outlet flow rate and adjusting it to a desired magnitude. A roller (peristaltic) pump can be used as a metering device in this application. When used with a specific tubing and rotational speed, prescribed volumetric output of the fragmented tissue will be exhausted.

A manifold attaches to the proximal end of the catheter to provide leak-free access pathways for the high pressure fluid supply, the exhaust pathway for fragmented tissue to be delivered to a collection reservoir, the pathway for fluid (either gas or liquid)

for inflation of balloon(s) at the distal end of the catheter (if desired), and the access port for introducing an auxiliary diagnostic or therapeutic device available to the physician. Such therapeutic devices may include a guidewire used to guide the catheter to its appropriate site in a vessel, tubule or cavity. A diagnostic device may include an ultrasound catheter or an angioscope. Contrast agents, thrombolytic drugs, or other drugs may also be delivered to the lesion site either using the exhaust lumen or the high pressure supply tube. A balloon inflation means can be connected to the manifold to deliver a gas or fluid to inflate a balloon(s) located at the distal end of the catheter. Such balloon(s) can serve to either reduce immobilization of fragmented tissue or for dilation of the lesion. The balloon inflation means can be a sterile syringe or other device available for inflation of angioplasty catheter balloons.

According to the second embodiment of the present invention (FIG. 3), there is provided a thrombectomy or tissue removal catheter having a manifold at the proximal end and having a distal end which enters percutaneously into a blood vessel, tubule, or cavity of the body in order to fragment thrombus or other tissue obstruction and remove the fragments out of the body. The saline or high pressure fluid enters the catheter manifold and is routed via a high pressure conduit such as a hypo tube or polyamide tube to the distal end of the catheter where it exits through at least one orifice, which forms one or more jet(s) of high pressure fluid which are directed at the opening of an exhaust lumen. The exhaust lumen carries the fragmented tissue from the distal end of the catheter to the manifold which is located outside the body. The high pressure tubing forms a loop at the

distal tip with the plane of the loop being perpendicular to the axis of the catheter shaft. Holes drilled into the loop form the orifices which direct jets of saline in a proximal direction back towards the opening of the exhaust lumen. One or more of these jets provides the stagnation pressure at the opening of the exhaust lumen to drive a volumetric outflow of fragmented tissue, which can be greater than the flow rate of the high pressure saline. The stagnation pressure can be higher than one atmosphere, thereby generating a greater exhaust rate than can be accomplished by creating a vacuum at the proximal end of the exhaust lumen with a vacuum pump. The development of a stagnation pressure at the opening of the exhaust requires a pressure within the high pressure tubing at the distal end to be at least 500 psi with improved results occurring with pressures of over 1000 psi. In order to obtain significant entrainment of thrombus or tissue into the high velocity jet(s) as a result of their localized low pressure, it is necessary to operate the device with the pressure of the fluid in the high pressure tubing at the distal end, being at least 500 psi. Without high pressure, the amount of entrainment of surrounding tissue and thrombus, which moves into the jet for ablation, is minimal and the catheter would require direct contact of the jet or juxtaposition with the material to be fragmented. A distal pressure of over 1000 psi for the high pressure fluid provides improved entrainment of tissue into the jet for fragmentation. The formation of a loop in the distal portion of the high pressure tubing provides the catheter with the capability of following over a standard guidewire (which then would be located within the loop), and still maintaining unobstructed access to the thrombus or tissue entrained in a jet, as well as access for at

least one jet unobstructed by the guidewire to impinge on the exhaust lumen and generate the stagnation pressure to drive tissue fragment exhaust. The guidewire can follow through the exhaust lumen of the catheter to efficiently
5. utilize the available space and minimize the diameter of the catheter shaft. The distance between the orifice(s) and the entrance to the exhaust lumen is another important variable in determining the amount of stagnation pressure generated. A distance of one half to
10 five millimeters will provide adequate stagnation pressure to drive exhaust, and still provide enough space for thrombus or tissue to become entrained for fragmentation. As this distance becomes greater, there is a tendency towards significantly less stagnation
15 pressure; as the distance becomes smaller, little or no benefit is gained due to limited entrainment.

In the third embodiment of the invention (FIG. 8), there is provided a tissue removal catheter similar in every way to that of the second embodiment except that
20 the orifice(s) are located a further distance away from the opening to the exhaust lumen. At a distance of greater than five millimeters, the jet spray pattern tends to fan out with much of the spray missing the exhaust lumen and also a great loss in its kinetic
25 energy. Even though this device does not generate enough stagnation pressure to drive the exhaust flow, it still will be fully capable of entraining thrombus or tissue into the jet as long as the pressure within the high pressure tubing at the distal end is greater than
30 500 psi. The catheter, therefore, does not have to be brought into juxtaposition or contact with thrombus or tissue for it to fragment the tissue. The localized negative pressure will draw the thrombus or tissue into

the jet. Exhaust can be accomplished in this case by applying a vacuum or suction as needed.

According to the fourth embodiment of the invention (FIG. 9), there is provided a catheter similar to that of the second embodiment except with the addition of the following feature which can add to its performance. This device provides additional radially directed jets of fluid to the distal end of the catheter. These additional jets are directed with radial component outwards in order to help dislodge the thrombus or tissues from the blood vessel, tubule, or cavity. The outward jets are of a lower velocity than the jets which direct fluid at the opening of the exhaust lumen. The lower velocity jet(s) will not damage the vessel wall or cause damage to the blood which they may contact. Approximately three jets will clean the perimeter of a vessel or tubule, and will set up a recirculation pattern where the fluid from the radial jets is directed to form a path leading toward the localized low pressure region of the high velocity jets directed at the opening of the exhaust lumen. This recirculation pattern helps to clean the vessel or tubule with greater efficiency.

According to the fifth embodiment of the invention (FIG. 14), there is provided a catheter similar to that of the first or fourth embodiment except that the following additional features have been added to help performance in specific applications. The catheter shaft tubing can be constructed of plastic with a dual lumen which can provide one lumen for exhaust in a manner similar to the second embodiment and a second lumen for carrying a fluid (either gas or fluid) for inflation of a balloon located on the distal end of the catheter. The balloon can be constructed of latex, silicone, polyurethane, or other elastic material and can serve to

center the catheter, as well as isolate the distal end of the catheter so that fragments cannot migrate past the balloon. A balloon of this type could be located either proximal or distal to the fluid jets and exhaust lumen opening or in both locations. A dilation balloon constructed out of polyolefin, polyethylene, polyvinylchloride, polyethylene terephthalate, or other high strength plastic could be similarly located at the distal end of the catheter. Such a balloon could be used to dilate a vessel lesion either before or after the catheter has removed tissue deposits such as thrombus. This catheter contains a separate tubing to carry the high pressure fluid from the manifold to the distal end to supply the high velocity jets.

According to the sixth embodiment of the invention (FIG. 15), there is provided a thrombus or tissue fragmentation catheter that does not remove the fragmented tissue. The device contains a high pressure fluid tube such as a hypo tube which delivers high pressure fluid to one or more orifices which direct jet(s) the fluid proximally toward the surface. The surface serves as a target for the jet(s), providing an element of safety to the catheter by prohibiting direct impingement of the jet on the wall of a blood vessel, tubule or duct. The jet has high velocity and low localized pressure due to the high fluid pressure of at least 500 psi in the high pressure tube. Therefore, the jet can both entrain tissue onto the jet, and break up the tissue or thrombus into fragments. No lumen is available in this catheter for exhaust of the fragments. The impingement surface can be made with an opening, which would allow for guidewire passage although it is not required. The distal end of the hypo tube can be made into a loop to provide for guidewire passage

although it is not required. Fragments generated by this device can be allowed to remain in the vessel, tubule, or cavity, may embolize with blood flow, or may be washed out using other means.

5 According to the seventh embodiment of the invention, which applies to previous embodiments that contain an exhaust lumen, there is provided a catheter with a high pressure tube to deliver high pressure fluid from the proximal end of the catheter to the distal end
10 where the fluid is directed by one or more orifices at high velocity onto the distal opening of an exhaust lumen. The pressure in the high pressure tubing at the distal end is at least 500 psi in order to effectively break up the thrombus or tissue deposit. A suction may
15 be applied to the proximal end of the exhaust lumen with a vacuum pump to provide for removal of the fragmented thrombus or tissue, or a roller pump may be used to accomplish a similar effect. The pressure in the high pressure tubing at the distal end may be greater than 500
20 psi with improved tissue fragmentation occurring at pressures over 1000 psi. Entrainment of tissue such as thrombus into the localized low pressure region of the high velocity jet allows the device to operate effectively without requiring direct contact or
25 juxtaposition of the catheter with neighboring tissue deposit. The distal end of the high pressure tube may form a small arc in order to direct the jet of high pressure fluid proximally toward the opening of the exhaust lumen or it may form a loop perpendicular to the
30 axis of the catheter shaft in order to direct several jets of fluid rearwards. The loop allows the catheter to follow over a guidewire to reach the lesion site and to effectively fragment thrombus around the entire perimeter of the guidewire, vessel, tubule, or body cavity.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects of the present invention and many of the attendant advantages of the present invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, in which like reference numerals designate like parts throughout the figures thereof and wherein:

FIG. 1 is a schematic view of the present invention, including a thrombectomy or tissue removal catheter;

FIG. 2 illustrates a cross-sectional view of the manifold;

FIG. 3 illustrates a cross-sectional view of distal end of the present invention;

FIG. 4 illustrates an end view of the loop of FIG. 3;

FIG. 5 illustrates a cross-sectional view along line 5-5 of FIG. 3;

FIG. 6 illustrates a cross-sectional view along line 6-6 of FIG. 3;

FIG. 7 illustrates a cross-sectional view along line 7-7 of FIG. 3;

FIG. 8, an alternative embodiment, illustrates a distal end;

FIG. 9, an alternative embodiment, illustrates another distal end;

FIG. 10 illustrates a cross-sectional view along line 10-10 of FIG. 9;

FIG. 11 illustrates a cross-sectional view along line 11-11 of FIG. 9;

FIG. 12 illustrates a cross-sectional view along line 12-12 of FIG. 9;

FIG. 13 illustrates a cross-sectional view along line 13-13 of FIG. 9;

FIG. 14, an alternative embodiment, illustrates a distal tip;

FIG. 15 illustrates a cross-sectional view along line 15-15 of FIG. 14;

5 FIG. 16, an alternative embodiment, illustrates a distal end; and,

FIG. 17 illustrates a cross-sectional view along line 17-17 of FIG. 16.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

10 FIG. 1 is a schematic view of one embodiment of a thrombectomy and tissue removal device and method 10 employing the present invention. The details supplied herein should be taken as representative and not limiting of the many embodiments which may be efficaciously
15 employed within the scope of the present invention.

Catheter system 10 has a standard two-lumen catheter 12, which is extruded of a flexible material, such as polyolefin, PTFE, PVC, polyurethane, nylon, or other suitable material in the normal fashion. Near the
20 distal end of catheter 12 can be located inflatable balloon 14, which is preferably an elastic balloon having no predefined outside diameter size limitation upon inflation. In this manner, balloon 14 can conform to the exact dimensions of the vessel to hold distal end 16 of
25 catheter 12 in a fixed position. Alternatively, inflatable balloon 14 can be an inelastic balloon with a predefined shape and size to permit it to be also used for dilation as in transluminal angioplasty. Distal end 16 of catheter 12 is described in more detail in the
30 figures that follow. Alternatively, the catheter 12 can be made without balloon 14 at all.

Guidewire 18, is optionally available for positioning the catheter 12 as an over-the-wire system, or other diagnostic or therapeutic devices can be used

along with the catheter, and may occupy the same lumen as occupied by a guidewire 18. Guidewire 18 passes through the larger of the two lumens of catheter 12 as described in more detail below.

5 A manifold 20 is molded of a rigid plastic or other suitable material. The main branch couples to the larger of the lumens of catheter 12, and has a standard seal assembly 22 applied to the proximal end to sealingly engage the catheter 12. The guidewire 18 sealingly
10 engages manifold 20 by a standard seal 23.

 Secondary branch 24 is also coupled to the larger lumen to provide for evacuation of the emulsified thrombus deposits. Secondary branch 24 sealingly engages
15 distal end 26 of effluent tubing 28 via seal assembly 30.

 The flow of effluent through flexible effluent tubing 28 is metered by rollers 32, 34, and 36 as rotated by rotor 38 in the direction of arrows 40 or any other type of controlled metering structure. It must be
20 emphasized that the effluent in flexible tubing 28 is under pressure and, therefore, need not be pumped by peristaltic pump assembly 42, which merely restricts and meters the flow. This metering could equally well be accomplished with a timed mechanical valve (not shown) which controls the outflow rate. After metering, the
25 effluent from flexible effluent tubing 28 is deposited in tissue fragment collection reservoir 44.

 Another secondary branch 46 of manifold 20 is sealingly coupled to inflation tubing 48 by seal assembly 50. Inflation and deflation of inflatable
30 balloon 14 is controlled by balloon inflation fluid means 52 in the customary manner.

 The saline solution used to emulsify the thrombus deposit is derived from the standard sterile saline container 54, which may be commercially available. The

saline solution is transferred to the high pressure supply means 56 via tubings and coupling assembly 58. This is a low pressure fluid path.

5 The high pressure supply means 56 can be a positive displacement piston pump 58. It is made to be completely disposable for sanitary reasons. The pump 58 can operate under pulsatile or steady flow.

10 The high pressure output of disposable pump 58 is coupled by a high pressure liquid tube 60 of the catheter by a connection 62 made at another secondary branch 62 of the manifold 20.

15 FIG. 2 is a cross sectional view of manifold assembly 20 which includes the proximal end of the flexible dual lumen catheter shaft tubing member 12. This component can be molded as two halves, which are solvent-bonded together, the view also happens to show one of the two possible halves. As described above, catheter 12 is a two lumen catheter. In the preferred mode, each of the two lumens has two distinct functions.
20 Therefore, manifold 20 serves to provide passage for a high pressure tubing and balloon inflation through one lumen and passage of a guide wire and evacuation through the other lumen.

25 The larger lumen of catheter 12 is lumen 64. It is used for passage of guide wire 18 (not shown in this view) and for evacuation of effluent and possible passage of a therapeutic angioplasty dilatation catheter, dilatation guidewire, angioscopic probe, or other therapeutic or diagnostic device. Lumen 64 extends
30 through manifold 20 to the proximal end of the manifold and provides passage of a guide wire or other diagnostic or therapeutic device. Guide wire 18 is sealed by compressible circular seal 66 which is compressed by surface 68 as threaded knob 70 is tightened on

threads 72. It is important to seal guide wire 18 in this way as guide wire 18 must be movable with respect to catheter 12 to properly manipulate distal tip 16 of catheter 12 into position.

5 Lumen 64 is also terminated at secondary branch 24. This is accomplished by removing a portion of the outer wall of lumen 64 at point 74. This provides fluid coupling between lumen 64 and lumen 76 of secondary branch 24.

10 The smaller lumen of catheter 12 is lumen 78. One of its functions is as a fluid passageway for the inflation of balloon 14. This function is accomplished by removing a portion of the outer wall of lumen 78 at point 80 to fluid couple lumen 78 to lumen 82 of
15 secondary branch 46.

 The remaining purpose of lumen 78 is to provide for passage of metallic tubing 84. Because of the extremely high pressures involved, the saline solution is conveyed in a metallic tubing 84, which is preferably stainless
20 steel hypo tubing. To handle the pressures involved, the hypo tubing is run as a continuous length along catheter 12. The proximal end of metallic tubing 84 passes through the outer wall of lumen 78 at point 89 and into secondary branch 62. A larger diameter hypo tube 60
25 is brazed onto hypo tube 84 at point 86. Alternatively, the larger diameter hypo tube 60 may be attached to hypo tube 84 with a removable connection. This larger tubing is covered by protective plastic tubing 88. Manifold 20 is solvent-bonded together prior to assembly of the
30 catheter, and points 90, 91, 92, 93 and 94 are used to introduce an adhesive which serves as a seal to separate each path and each lumen. Point 95 shows the bonding of the outer plastic tube which surrounds the high pressure supply tube to the manifold.

FIG. 3 illustrates a sectional view of a thrombectomy or tissue removal catheter distal end 16 including an outer plastic sheath 102, a tip 104 having a large external orifice 106, a septum 108 encompassing a hypo tube 110 and holding it to the inner surface of the outer plastic sheath 102, and effluent lumen 112 incorporating the large external orifice 106 and further formed by the inner surface of the outer plastic sheath 102 and the septum 108. A loop 114 is located at the distal end of the hypo tube 110. The loop 114 allows the catheter to follow easily over a guidewire, but the distal end of the hypo tube is not required to be looped. Orifices 116, 118 and 120 serve as jets to direct saline into the external orifice 106 which communicates with the effluent lumen 112.

The saline flow 124 is directed out of the orifice jets 116, 118 and 120 in the loop 114 and back toward the orifice opening 106 to the effluent lumen 112. A beveled surface 126 is included on the outer portion of the tip 104 to help direct saline flow to the effluent lumen 112. There are no saline jets shooting in an outward direction. Since some blood vessels and tubules are smaller in diameter, one does not require the outward shooting orifice jets. Also, the absence of outward shooting orifice jets makes this design safe with low risk of vessel damage or spasm. The simplicity of the design allows the device to be made with a small diameter at the tip (i.e., 4F or .052"). The catheter can be made with diameters ranging from 2F to 10F (.026" - .130") or larger if desired. The loop 114 in the hypo tube 110 still allows the device to follow a guidewire without causing damage to the vessel. More than three orifices could be used with some tradeoffs of advantages and disadvantages, but this will not offer much advantage,

and will cause more orifices of the same size and operating pressure will result in a greater effluent flow rate to be removed due to the additional jets. More orifices of a smaller diameter will result in a greater
5 chance of plugging and a lower penetration distance capability for the jetted saline in order to maintain the total jet flow rate at an appropriate level. If the total jet flow rate becomes too large, the pressure energy loss in the high pressure tube becomes very large
10 and requires excessive liquid pressure at the proximal end of the high pressure tube. Two jets could be used instead of three, but the ability of the catheter to clean around the entire vessel perimeter becomes hampered. A single jet does not work well when a
15 guidewire is in place since the guidewire blocks entry of thrombus. Also, a loop is very helpful to allow the catheter to track closely over a guidewire without inducing trauma to the vessel.

This catheter when operated with a distal pressure
20 in the high pressure lumen of at least 500 psi will entrain thrombus or tissue deposit into the one or more proximally shooting saline flow jet(s) 124 before it reaches the opening 106 to the evacuation lumen 112. If the distance from the orifice(s) to the opening of the
25 evacuation lumen is relatively close such as 1-5mm with an average distance of approximately 3 mm, the jet(s) will generate a stagnation pressure at openings which can exceed 1 atmosphere, and will drive the evacuation of the fragmented tissue out of the evacuation lumen 112 without
30 the need for a vacuum pump or any application of suction. Instead, a metering means, such as that of FIG. 1, can be applied to the proximal end of the evacuation lumen 112 to control the rate of evacuation as desired. The roller pump 42 of FIG. 1 can serve as this metering means to

control the rate of evacuation such that it is greater than, equal to, or less than the flow rate of saline exiting the orifices at the distal end of the high pressure tube 110.

5 FIG. 4 illustrates an end view of the loop 110 where all numerals correspond to those elements previously described.

10 FIG. 5 illustrates a cross-sectional view along line 5-5 of FIG. 3 illustrating the orifices 116-120 where all other numerals correspond to those elements previously described.

15 FIG. 6 illustrates a cross-sectional view along line 6-6 of FIG. 3 illustrating the exhaust lumen 112 in the area of the tip 104. All other numerals correspond to those elements previously described.

20 FIG. 7 illustrates a cross-sectional view along line 7-7 of FIG. 3 illustrating the exhaust lumen 112 in the distal area of the catheter 12. All other numerals correspond to those elements previously described.

25 FIG. 8 illustrates a distal end 130 having like and similar component members with the exception that the hypo tube now labeled 132 extends a greater distance past the tip member 104. All other numerals correspond to those elements previously described.

30 If the distance from the orifice(s) 116-120 to the opening 106 of the evacuation lumen 112 is large, such as greater than 5 mm, the catheter will loose much of the stagnation pressure formed from the impingement of the liquid jets 124 on the opening to the exhaust lumen 106. Suction may be applied to the proximal end of the evacuation lumen to provide for removal of fragmented tissue. The device, however, will still entrain thrombus or tissue deposit into the localized low pressure region of the liquid jets 124 as long as the pressure at the

distal end of the high pressure tubing is at least 500 psi.

FIG. 9 illustrates an alternative embodiment of a distal end 200 that is similar to that illustrated in FIG. 3 except that a balloon has been added onto the plastic sheath proximal to the jet orifice(s) 116-120, and a catheter tip has been modified to provide for jets with a component directed radially outward of a lower energy than the proximally shooting jets which impinge on the opening of the evacuation lumen. The distal end 200 is comprised of a plastic sheath 202, a manifolded tip 204 having an inner manifolded tip member 206, and outer tip member 208 aligned over and about the inner manifolded tip member 206, a large external orifice 210, a septum 212 encompassing a hypo tube 214 and holding it to the inner surface of the outer plastic sheath 202, an effluent lumen 216 incorporating the large external orifice 210 and further formed by the inner surface of the outer plastic sheath 202 and the septum 212. A loop 218 is located at the distal end of the hypo tube 214. The loop 218 allows the catheter to follow easily over a guidewire, but the distal end of the hypo tube is not required to be looped. Jet orifices 220, 222 and 224 (see FIG. 10) serve to direct saline jets 234 into the large external orifice 210 which communicates with effluent lumen 216.

The tip 204 of the distal catheter end 200 has been modified to include both an inner manifold tip member 206 and outer tip body member 208 which provides a three stage manifolded tip 204 for reducing the pressure delivered to three radially outwardly aligned jet orifices 226, 228 and 230 illustrated in FIG. 13. This reduction in pressure provides for a lower velocity for these jets, and consequently, these radial jets 250, 251,

and 252 are less traumatic than the rearward shooting jets 220-224. The radial jets 250, 251 and 252 help to clean thrombus or tissue deposit from the walls of blood vessels or tubules and bring the deposit into the rearward directed jets for fragmentation and removal.

The saline or high pressure liquid enters the proximal end of the high pressure hypo tube 214 and flows to the distal end of the high pressure hypo tube 214. Some of the liquid flows out of an opening 232 in the high pressure tube 214 into the first manifold stage 236 and successive stages of the manifolded tip 204, and some liquid flows out of the orifice(s) 220-224 which direct the saline jet(s) flow 234 backwards toward the opening 210 to the effluent evacuation lumen 216. The fluid which enters the manifolded tip 204 still may possess significant localized kinetic energy which requires dissipation. As shown in this figure, the liquid is directed from the opening 232 and thence through the three stages of the manifolded tip 204 (i.e., three manifold spaces 236, 238 and 240 with flow resistance narrowings 242 between them as illustrated in FIGS. 11, 12 and 13). The liquid is then expelled radially through three exit side holes 226-230 of FIG. 13 with low velocity. Various manifold arrangements could be used to dissipate the kinetic and potential energy of the liquid prior to expelling the stream out of the catheter tip.

FIG. 10 illustrates a cross-sectional view along line 10-10 of FIG. 9 where all numerals correspond to those elements previously described.

FIG. 11 illustrates a cross-sectional view along line 11-11 of FIG. 9 showing a flow resistance narrowing 242 leading from the manifold space 236 to the

manifold space 238 of FIG. 12. All other numerals correspond to those elements previously described.

5 FIG. 12 illustrates a cross-sectional view along line 12-12 of FIG. 9 showing flow resistance narrowings 244, 246 and 248 between the manifold space 238 and the manifold space 240 of FIG. 13. All other numerals correspond to those elements previously described.

10 FIG. 13 illustrates a cross-sectional view along line 13-13 showing the manifold space 240 and the radial outward facing jet orifices 226, 228 and 230 in the walls of the outer tip member 208. All other numerals correspond to those elements previously described.

15 FIG. 14 illustrates a cross-sectional view of a distal tip end 300 similar to that illustrated in FIG. 9 except that a balloon 219 has been added to the plastic sheath 202 proximal to the jet orifices 220-224. All other numerals correspond to those elements previously described. The addition of a balloon is accomplished on
20 this or any other catheter end so identified to contain a lumen which can carry a fluid (either gas or liquid) from the proximal end of the catheter to a more distal location in approximation with a balloon. The plastic sheath 202 is constructed of a dual lumen plastic
25 construction where the balloon inflation lumen 213 (see FIG. 15) is the portion between the inner surface of the septum 212 and sheath 202. The high pressure hypo tubing 214 aligns in and utilizes the same balloon inflation lumen space 213 for efficiency. The
30 balloon 219 secures by adhesives 217 over and about the plastic sheath 202 and is inflated through an inflation port 215 (see FIG. 15) connected to the balloon inflation lumen 213.

FIG. 15 illustrates a cross-sectional view along line 15-15 of FIG. 14 where all numerals correspond to those elements previously described. Illustrated in particular is the balloon inflation port 215.

5 FIG. 16 illustrates a distal end 400 having a high pressure hypo tube 402 such as a metal hypo tube, polyamide tube or other high pressure tube provides a pathway for saline or other high pressure liquid from the proximal end to the distal end of the catheter. The
10 saline exits through one or more jet orifices 404, 406 or 408 (see FIG. 17) in the loop 410 and the high velocity jet streams 412 impinge upon the impingement surface 414 of a target body 416. The high velocity of the jet(s) streams 412 provides a localized low pressure
15 which serves to draw thrombus or other tissue deposits into the jet(s) streams 412 where it is fragmented into small pieces which will continue to get smaller as they are reintroduced into the high velocity jet streams 412. The impingement surface 414 provides a safety aspect to
20 the catheter by prohibiting the jet(s) streams 412 from coming into juxtaposition with the vessel cavity wall and causing unwanted trauma to healthy tissues. The target body 416 can be made as shown with a lumen 418 to allow for this catheter to pass over a standard guidewire in
25 order to reach the lesion site in the blood vessel, tubule, or body cavity. The device can consist of only one high velocity jet with the impingement surface made smaller in surface area, or it can have up to ten jets. The preferred number of jets is three in order to clean
30 thrombus around all sides of the vessel or tubule when a guidewire is in place. The device can be made without a guidewire lumen if desired. This device operates with a pressure in the distal end of the high pressure tube of at least 500 psi and preferably 1000-2000 psi. The high

5 tube pressure is necessary to generate the large localized negative pressure at the jet required to provide for entrainment of thrombus or tissue deposit into the jet(s). A plastic protective covering 420 may be used to provide resistance to vessel trauma and aligns over and about.

FIG. 17 illustrates an end view of the distal end 400 where all numerals correspond to those elements previously described.

10 Various modifications can be made to the present invention without departing from the apparent scope hereof.

WE CLAIM:

CLAIMS

1. A device for removing thrombus or other tissue from an occluded or obstructed biological or synthetic body vessel comprising:

- 5 a. a tubular member having a proximal end and a distal end, having a first passage and a second passage extended along the length thereof, each passage with a proximal and distal end;
- 10 b. the first passage comprising tubular means for carrying high pressure fluid from the proximal end to the distal end;
- c. the second passage comprising tubular means for carrying fluid and emulsified tissue from the distal end to the proximal end;
- 15 d. one or more fluid jets emanating from the distal end of the first passage impinges on the open distal end of the second passage, said fluid jet(s) providing stagnation pressure to drive the flow of emulsified tissue from the distal end of the second passage towards the proximal end of the second passage;
- 20 e. the proximal end of the first passage is connected to a high pressure fluid source; and,
- f. the opening proximal end of the second passage provides removal of the tissue fragments from the body.
- 25

2. The device of claim 1 wherein the tubular member is flexible to provide for passage of the tubular member along the body vessel.

30 3. The device of claim 1 wherein a metering means is connected to the proximal end of the second passage to control the flow of fluid and emulsified tissue at a rate of flow less than the rate of flow which would result without the metering means.

4. The device of claim 3 wherein the metering means consists of a roller pump which controls the outflow resistance in the second passage and hence controls the rate of flow of emulsified tissue.

5 5. The device of claim 3 wherein the metering means controls the rate of flow of fluid and emulsified tissue in the second passage at a rate of flow to approximately equal the rate of flow of high pressure fluid in the first passage.

10 6. The device of claim 3 wherein the metering means controls the rate of flow of fluid and emulsified tissue in the second passage at a rate of flow to less than the rate of flow of high pressure fluid in the first passage.

15 7. The device of claim 3 wherein the metering means controls the rate of flow of fluid and emulsified tissue in the second passage at a rate of flow to greater than the rate of flow of high pressure fluid in the first passage.

20 8. The device of claim 1 wherein one or more fluid jets emanating from the distal end of the first passage are directed with some radial component.

25 9. The device of claim 8 wherein the radially-directed jets have lower fluid velocity which tends to avoid injury to the body vessel.

30 10. The device of claim 8 wherein a metering means is connected to the tubular member to control the flow of fluid and emulsified tissue at a rate of flow less than the rate of flow which would result without the metering means.

11. The device of claim 1 wherein the high pressure fluid source is a positive-displacement piston pump.

12. The device of claim 11 wherein the piston pump provides the high pressure fluid flow in a largely pulsatile or periodic unsteady flow.

5 13. The device of claim 11 wherein the piston pump provides the high pressure fluid flow in a largely steady flow.

14. The device of claim 1 wherein the second passage also provides passage for a guidewire, ultrasound catheter, angioscopic catheter, or other catheter device.

10 15. The device of claim 1 wherein the distal end of the first passage is formed into an arcuate shape extending beyond the second passage to direct one or more jets onto the distal end of the second passage.

15 16. The device of claim 1 wherein the distal end of the first passage is formed into a toroidal shape which is oriented in a plane perpendicular to the axis of the tubular member.

20 17. The device of claim 16 wherein the toroidal shape facilitates movement of the tubular member along a guidewire, thereby directing the distal end of the tubular member in the body vessel.

25 18. The device of claim 16 wherein a plurality of fluid jets emanate from various points along the toroidal-shaped portion of the first passage; when a guidewire is in position through the toroidal shape, the jets are therefore oriented at various points circumferentially around the guidewire thereby decreasing any effect that the guidewire may have in shielding any tissue from the effects of the jets.

30 19. A device for removing thrombus or other tissue from an occluded or obstructed biological or synthetic body vessel comprising:

- a. a tubular member having a proximal end and a distal end, having a first passage and a second

passage extended along the length thereof, each passage with a proximal and distal end;

- 5 b. the first passage comprising tubular means for carrying high pressure fluid from the proximal end to the distal end;
- c. the second passage comprising tubular means for carrying fluid and emulsified tissue from the distal end to the proximal end;
- 10 d. one or more fluid jets emanating from the distal end of the first passage to produce a low pressure region which tends to bring the tissue towards the jet(s);
- e. the proximal end of the first passage is connected to a high pressure fluid source; and,
- 15 f. the open proximal end of the second passage provides removal of the tissue fragments from the body.

20 20. The device of claim 19 wherein the tubular member is flexible to provide for passage of the tubular member along the body vessel.

25 21. The device of claim 19 wherein a suction means is connected to the proximal end of the second passage to control the flow of fluid and emulsified tissue at a rate of flow greater than the rate of flow which would result without the suction means.

 22. The device of claim 21 wherein the suction means consists of a roller pump.

30 23. The device of claim 21 wherein the suction means controls the rate of flow of fluid and emulsified tissue in the second passage at a rate of flow to approximately equal the rate of flow of high pressure fluid in the first passage.

 24. The device of claim 21 wherein the suction means controls the rate of flow of fluid and emulsified

tissue in the second passage at a rate of flow to less than the rate of flow of high pressure fluid in the first passage.

5 25. The device of claim 21 wherein the suction means controls the rate of flow of fluid and emulsified tissue in the second passage at a rate of flow to greater than the rate of flow of high pressure fluid in the first passage.

10 26. The device of claim 19 wherein one or more fluid jets emanating from the distal end of the first passage are directed with some radial component.

 27. The device of claim 26 wherein the radially-directed jets have lower fluid velocity which tends to avoid injury to the body vessel.

15 28. The device of claim 26 wherein a suction means is connected to the tubular member to control the flow of fluid and emulsified tissue at a rate of flow less than the rate of flow which would result without the suction means.

20 29. The device of claim 19 wherein the high pressure fluid source is a positive-displacement piston pump.

 30. The device of claim 29 wherein the piston pump provides the high pressure fluid flow in a largely pulsatile or periodic unsteady flow.

25 31. The device of claim 29 wherein the piston pump provides the high pressure fluid flow in a largely steady flow.

30 32. The device of claim 19 wherein the second passage also provides passage for a guidewire, ultrasound catheter, angioscopic catheter or other catheter device.

 33. The device of claim 19 wherein the distal end of the first passage is formed into an arcuate shape

extending beyond the second passage to direct one or more jets onto the distal end of the second passage.

34. The device of claim 19 wherein the distal end of the first passage is formed into a toroidal shape which is oriented in a plane perpendicular to the axis of the tubular member.

35. The device of claim 34 wherein the toroidal shape facilitates movement of the tubular member along a guidewire, thereby directing the distal end of the tubular member in the body vessel.

36. The device of claim 34 wherein a plurality of fluid jets emanate from various points along the toroidal-shaped portion of the first passage; when a guidewire is in position through the toroidal shape, the jets are therefore oriented at various points circumferentially around the guidewire thereby decreasing any effect that the guidewire may have in shielding any tissue from the effects of the jets.

37. A device for removing thrombus or other tissue from an occluded or obstructed biological or synthetic body vessel comprising:

- a. a tubular member having a proximal end and a distal end, having a first passage extending along the length thereof, said first passage having a proximal and distal end;
- b. the first passage comprising tubular means for carrying high pressure fluid from the proximal end to the distal end;
- c. an impingement surface providing a target to safely dissipate fluid energy and prevent injury to the body vessel;
- d. one or more fluid jets emanating from the distal end of the first passage produce a low

pressure region which tends to bring the tissue towards the jet(s); and,

- e. the proximal end of the first passage is connected to a high pressure fluid source.

5 38. The device of claim 37 wherein a passage through said target facilitates movement of the target along a guidewire, thereby directing the distal end of the tubular member in the body vessel.

10 39. The device of claim 37 comprising additionally a second passage extended along the length thereof, said second passage having a proximal and distal end, said second passage comprising tubular means for providing communication between the proximal and distal ends of the tubular member.

15 40. A device for removing thrombus or other tissue from an occluded or obstructed biological or synthetic body vessel comprising:

- a. a tubular member having a proximal end and a distal end, having a first passage and a second passage and a third passage extended along the length thereof, each passage with a proximal and distal end;
- 20 b. the first passage comprising tubular means for carrying high pressure fluid from the proximal end to the distal end;
- 25 c. the second passage comprising tubular means for carrying fluid and emulsified tissue from the distal end to the proximal end;
- 30 d. the third passage comprising tubular means for providing communication between the proximal and distal ends of the tubular member;
- e. one or more fluid jets emanating from the distal end of the first passage impinges on the open distal end of the second passage, said

fluid jet(s) providing stagnation pressure to drive the flow of emulsified tissue from the distal end of the second passage towards the proximal end of the second passage;

- 5 f. the proximal end of the first passage is connected to a high pressure fluid source; and,
 g. the open proximal end of the second passage provides removal of the tissue fragments from the body.

10 41. The device of claim 40 wherein positioning or isolation means such as a balloon is attached to the tubular member at a point proximal to the fluid jets, providing positioning means from the jets by tending to center the distal end of the tubular member in the body
15 vessel or isolation means tending to prevent passage of liquid and emulsified tissue past said means in the body vessel, said positioning or isolation means communicating with the distal end of the third passage, said
20 positioning or isolation means thereby being actuated from the proximal end of the tubular member by communication with the third passage.

 42. The device of claim 40 wherein dilation means such as a balloon is attached to the tubular member, providing for dilation of the body vessel, said dilation
25 means communicating with the distal end of the third passage, said dilation means thereby being actuated from the proximal end of the tubular member by communication with the third passage.

 43. The device of claim 40 wherein the first
30 passage comprises a metal tube.

 44. The device of claim 40 wherein the first passage comprises a tube constructed of a high-strength polymer such as polyamide or a composite material.

45. The device of claim 43 wherein the tubular member is flexible, providing for passage of the tubular member along the body vessel; a 2-lumen extruded polymeric tube comprises the second and third passages; the metal tube comprising the first passage is contained within the third passage; the distal end of the first passage is formed into a toroidal shape which is oriented in a plane perpendicular to the axis of the tubular member; 3 jets emanate from the toroidal-shaped portion of the metal tube; a guidewire can pass through the second passage of the tubular member and through the toroidal-shaped portion of the metal tube thereby directing the distal end of the tubular member in the body vessel; a metering means consisting of a roller pump controls the flow of fluid and emulsified tissue in the second passage at a rate of flow approximately equal to the rate of flow of high pressure fluid in the first passage; the high-pressure fluid source comprises a positive-displacement piston pump providing largely pulsatile flow.

46. The device of claim 45 wherein the tubular member and the piston pump are sterile; a nonsterile motor and motor control system operate the piston pump; a sterile bag of saline supplies fluid to the piston pump; the exhausted fluid and tissue is collected in a bag; tubing connects the tubular member, piston pump, supply bag, roller pump and exhaust bag; the tubular member can disconnect from the piston pump for replacement.

47. The device of claim 45 wherein three additional fluid jets having lower fluid velocity are directed radially.

48. A device for removing thrombus or other tissue from an occluded or obstructed biological or synthetic body vessel comprising:

- 5 a. a tubular member having a proximal end and a distal end, having a first passage and a second passage and a third passage extended along the length thereof, each passage with a proximal and distal end;
- 10 b. the first passage comprising tubular means for carrying high pressure fluid from the proximal end to the distal end;
- c. the second passage comprising tubular means for carrying fluid and emulsified tissue from the distal end to the proximal end;
- 15 d. the third passage comprising tubular means for providing communication between the proximal and distal ends of the tubular member;
- e. one or more fluid jets emanating from the distal end of the first passage produce a low pressure region which tends to bring the tissue towards the jet(s);
- 20 f. the proximal end of the first passage is connected to a high pressure fluid source; and,
- g. the open proximal end of the second passage provided removal of the tissue fragments from the body.
- 25

49. The device of claim 48 wherein positioning or isolation means such as a balloon is attached to the tubular member at a point proximal to the fluid jets, providing positioning means for the jets by tending to center the distal end of the tubular member in the body vessel or isolation means tending to prevent passage of liquid and emulsified tissue past said means in the body vessel, said positioning or isolation means communicating

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with the distal end of the third passage, said positioning or isolation means thereby being actuated from the proximal end of the tubular member by communication with the third passage.

5 50. The device of claim 48 wherein dilation means such as a balloon is attached to the tubular member, providing for dilation of the body vessel, said dilation means communicating with the distal end of the third
10 passage, said dilation means thereby being actuated from the proximal end of the tubular member by communication with the third passage.

51. The device of claim 48 wherein the first passage comprises a metal tube.

15 52. The device of claim 48 wherein the first passage comprises a tube constructed of a high-strength polymer such as polyamide or a composite material.

53. The device of claim 51 wherein the tubular member is flexible, providing for passage of the tubular member along the body vessel; a two-lumen extruded
20 polymeric tube comprises the second and third passages; the metal tube comprising the first passage is contained within the third passage; the distal end of the first passage is formed into a toroidal shape which is oriented in a plane perpendicular to the axis of the tubular
25 member; three jets emanate from the toroidal-shaped portion of the metal tube; a guidewire can pass through the second passage of the tubular member and through the toroidal-shaped portion of the metal tube thereby directing the distal end of the tubular member in the
30 body vessel; a metering means consisting of a roller pump controls the flow of fluid and emulsified tissue in the second passage at a rate of flow approximately equal to the rate of flow of high pressure fluid in the first passage; the high-pressure fluid source comprises a

positive-displacement piston pump providing largely pulsatile flow.

54. The device of claim 53 wherein the tubular member and the piston pump are sterile; a nonsterile motor and motor control system operate the piston pump; a sterile bag of saline supplies fluid to the piston pump; the exhausted fluid and tissue is collected in a bag; tubing connects the tubular member, piston pump, supply bag, roller pump, and exhaust bag; the tubular member can disconnect from the piston pump for replacement.

55. The device of claim 53 wherein three additional fluid jets having lower fluid velocity are directed radially.

56. A device for removing thrombus or other tissue from an occluded or obstructed biological or synthetic body vessel comprising:

- a. a tubular member having a proximal end and a distal end, having a first passage and a second passage extended along the length thereof, each passage with a proximal and distal end;
- b. the first passage comprising tubular means for carrying high pressure fluid from the proximal end to the distal end;
- c. the second passage comprising tubular means for carrying fluid and emulsified tissue from the distal end to the proximal end;
- d. one or more fluid jets emanating from the distal end of the first passage impinges on the open distal end of the second passage, the fluid in the first passage being under high pressure greater than approximately 500 psi, providing sufficient energy in said jets to cut or emulsify harder tissue;

5 e. the proximal end of the first passage is connected to a high pressure fluid source, aid source providing fluid at pressure sufficient to supply the distal end of the first passage with fluid at greater than approximately 500 psi, allowing for pressure losses along the first passage; and,

10 f. the open proximal end of the second passage provides removal of the tissue fragments from the body.

57. The device of claim 56 wherein the tubular member is flexible to provide for passage of the tubular member along the body vessel.

15 58. The device of claim 56 wherein a suction means is connected to the proximal end of the second passage to control the flow of fluid and emulsified tissue at a rate of flow greater than the rate of flow which would result without the suction means.

20 59. The device of claim 58 wherein the suction means consists of a roller pump.

25 60. The device of claim 58 wherein the suction means controls the rate of flow of fluid and emulsified tissue in the second passage at a rate of flow to approximately equal the rate of flow of high pressure fluid in the first passage.

30 61. The device of claim 58 wherein the suction means controls the rate of flow of fluid and emulsified tissue in the second passage at a rate of flow to less than the rate of flow of high pressure fluid in the first passage.

62. The device of claim 58 wherein the suction means controls the rate of flow of fluid and emulsified tissue in the second passage at a rate of flow to greater

than the rate of flow of high pressure fluid in the first passage.

5 63. The device of claim 56 wherein one or more fluid jets emanating from the distal end of the first passage are directed with some radial component.

64. The device of claim 63 wherein the radially-directed jets have lower fluid velocity which tends to avoid injury to the body vessel.

10 65. The device of claim 63 wherein a suction means is connected to the tubular member to control the flow which would result without the suction means.

66. The device of claim 56 wherein the high pressure fluid source is a positive-displacement piston pump.

15 67. The device of claim 66 wherein the piston pump provides the high pressure fluid flow in a largely pulsatile or periodic unsteady flow.

20 68. The device of claim 66 wherein the piston pump provides the high pressure fluid flow in a largely steady flow.

69. The device of claim 56 wherein the second passage also provides passage for a guidewire, ultrasound catheter, angioscopic catheter or other catheter device.

25 70. The device of claim 56 wherein the distal end of the first passage is formed into an arcuate shape extending beyond the second passage to direct one or more jets onto the distal end of the second passage.

30 71. The device of claim 56 wherein the distal end of the first passage is formed into a toroidal shape which is oriented in a plane perpendicular to the axis of the tubular member.

72. The device of claim 71 wherein the toroidal shape facilitates movement of the tubular member along a

guidewire, thereby directing the distal end of the tubular member in the body vessel.

73. The device of claim 72 wherein a plurality of fluid jets emanate from various points along the toroidal-shaped portion of the first passage; when a guidewire is in position through the toroidal shape, the jets are therefore oriented at various points circumferentially around the guidewire thereby decreasing any effect that the guidewire may have in shielding any tissue from the effects of the jets.

74. A device for removing thrombus or other tissue from an occluded or obstructed biological or synthetic body vessel comprising:

- a. a tubular member having a proximal end and a distal end, having a first passage and a second passage, and a third passage extended along the length thereof, each passage with a proximal and distal end;
- b. the first passage comprising tubular means for carrying high pressure fluid from the proximal end to the distal end;
- c. the second passage comprising tubular means for carrying fluid and emulsified tissue from the distal end to the proximal end;
- d. the third passage comprising tubular means for providing communication between the proximal and distal ends of the tubular member;
- e. one or more fluid jets emanating from the distal end of the first passage impinges on the open distal end of the second passage, the fluid in the first passage being under high pressure greater than approximately 500 psi, providing sufficient energy in said jets to cut or emulsify harder tissue;

5 f. the proximal end of the first passage is connected to a high pressure fluid source, said source providing fluid at pressure sufficient to supply the distal end of the first passage with fluid at greater than approximately 500 psi, allowing for pressure losses along the first passage; and,

10 g. the open proximal end of the second passage provides removal of the tissue fragments from the body.

15 75. The device of claim 74 wherein positioning or isolation means such as a balloon is attached to the tubular member at a point proximal to the fluid jets, providing positioning means for the jets by tending to center the distal end of the tubular member in the body vessel or isolation means tending to prevent passage of liquid and emulsified tissue past said means in the body vessel, said positioning or isolation means communicating with the distal end of the third passage, said
20 positioning or isolation means thereby being actuated from the proximal end of the tubular member by communication with the third passage.

25 76. The device of claim 74 wherein dilation means such as a balloon is attached to the tubular member, providing for dilation of the body vessel, said dilation means communicating with the distal end of the third passage, said dilation means thereby being actuated from the proximal end of the tubular member by communication with the third passage.

30 77. The device of claim 74 wherein the first passage comprises a metal tube.

78. The device of claim 74 wherein the first passage comprises a tube constructed of a high-strength polymer such as polyamide or a composite material.

35 DOC/PAT/P111

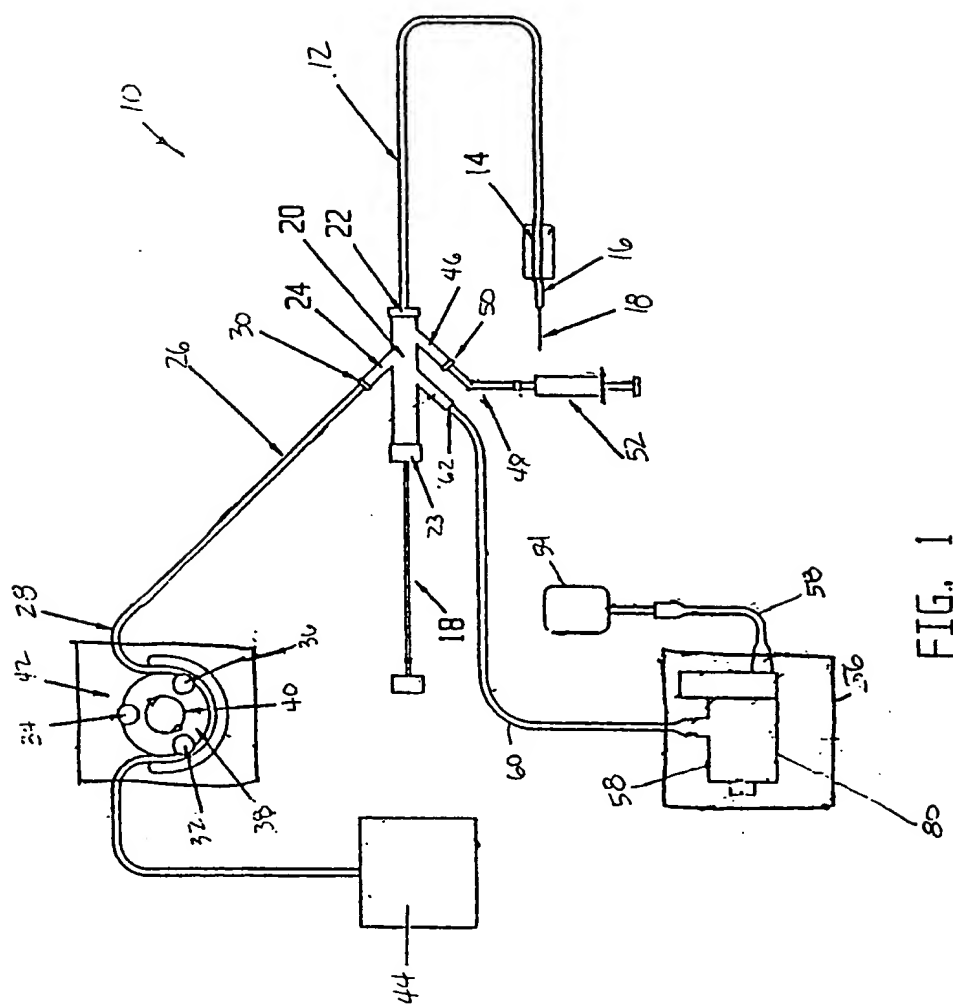


FIG. 1

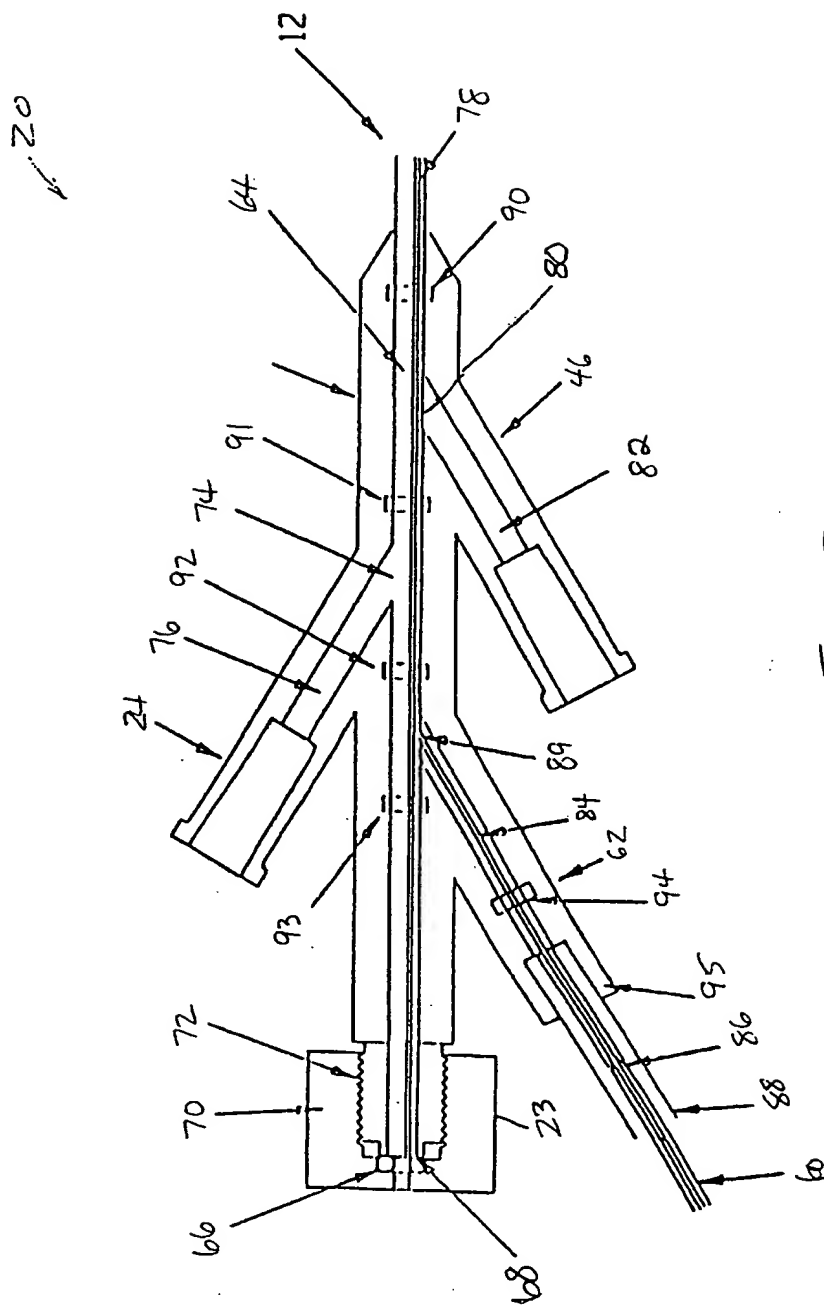


FIG. 2

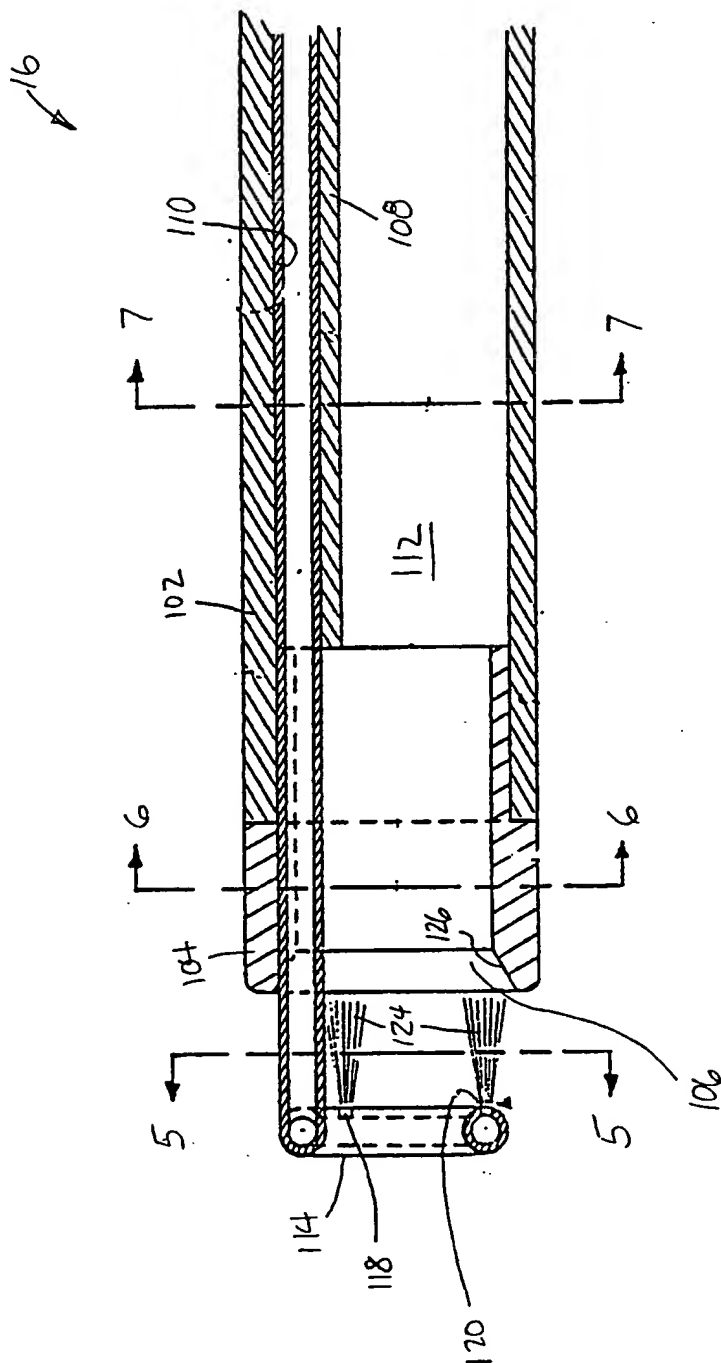


FIG. 3

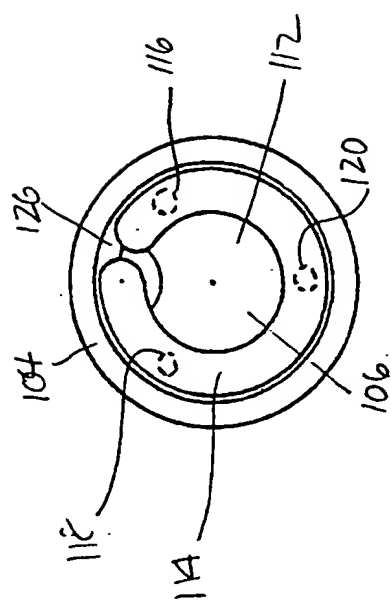


FIG. 4

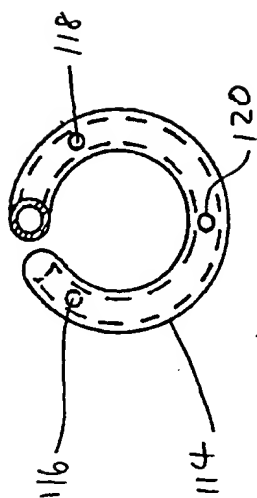


FIG. 5

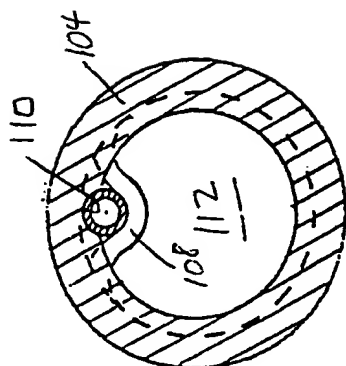


FIG. 6

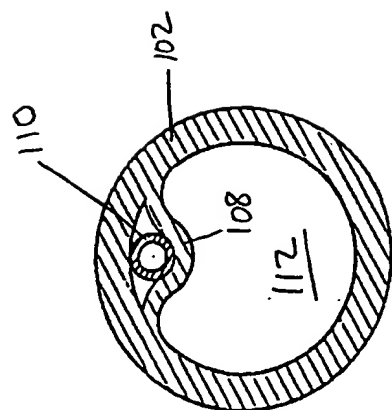


FIG. 7

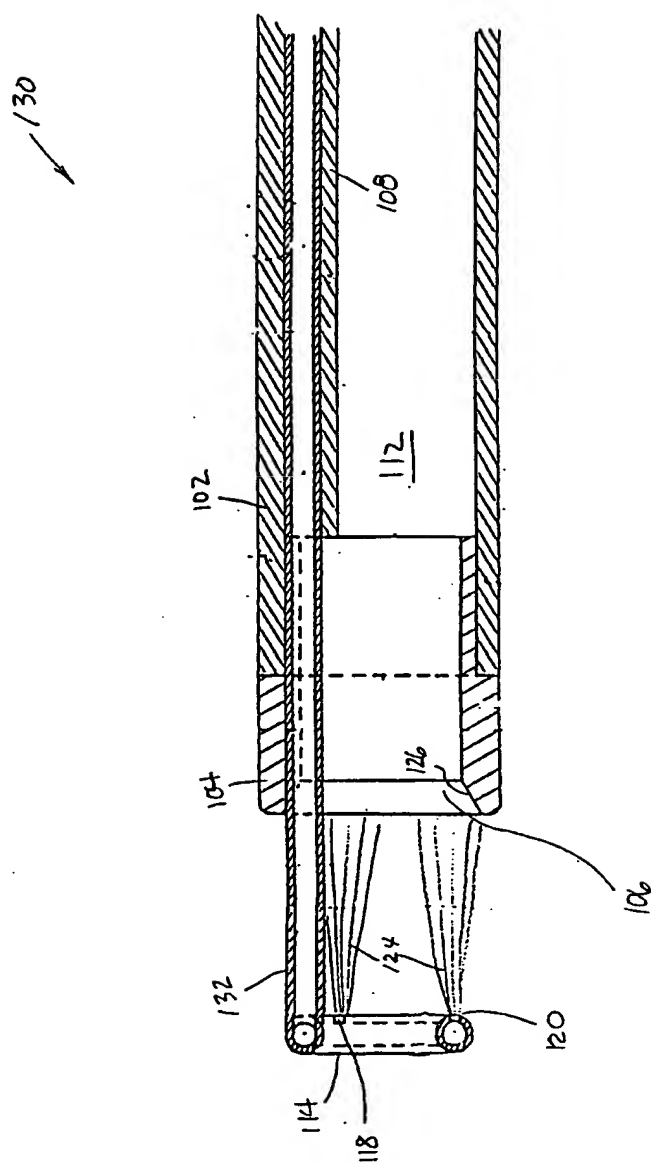
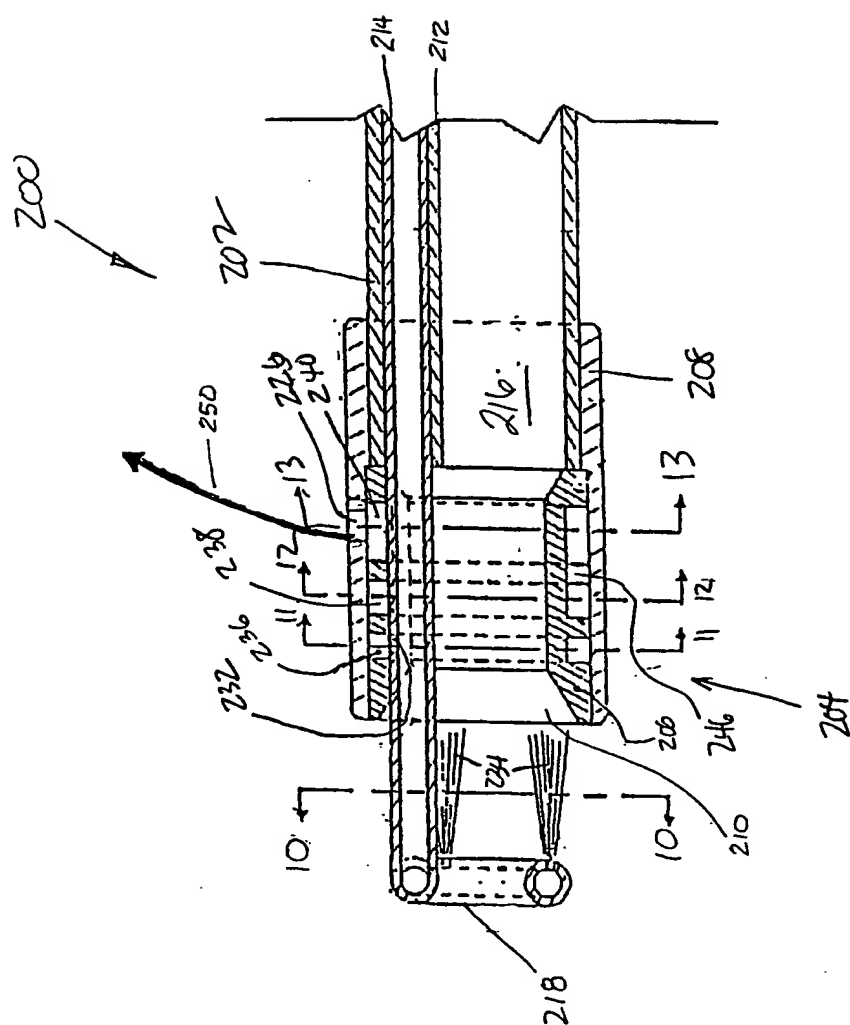


FIG. 8



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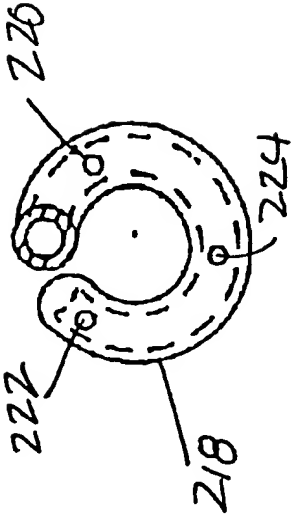


FIG. 10

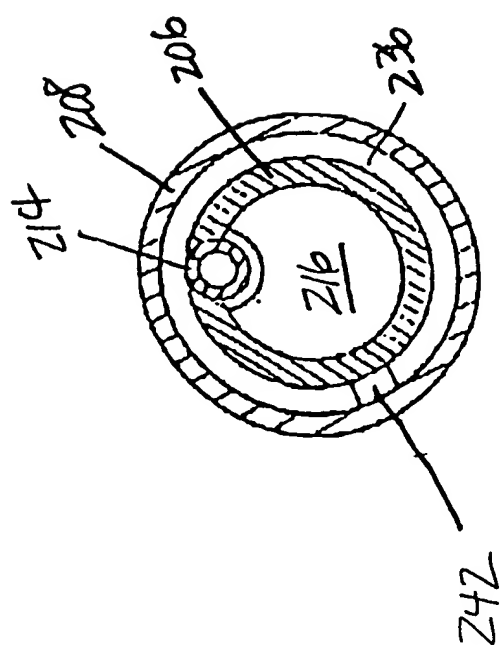


FIG. 11

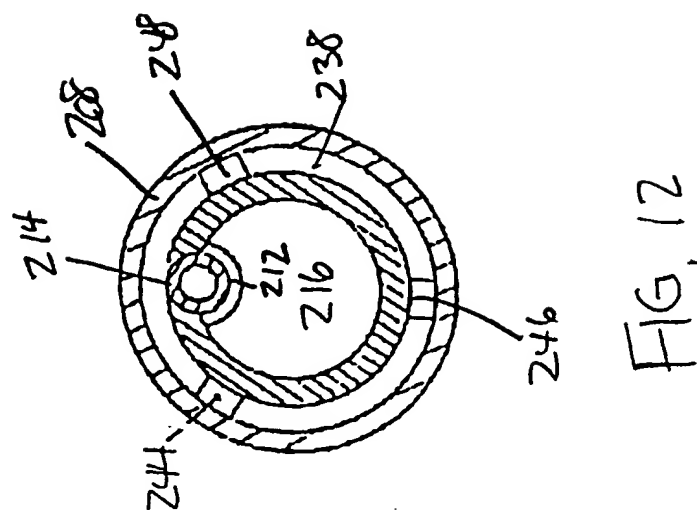


FIG. 12

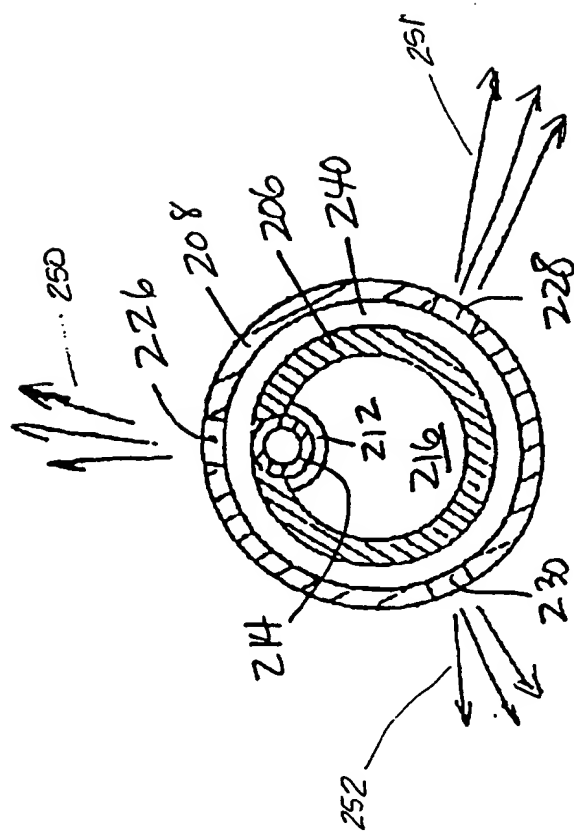
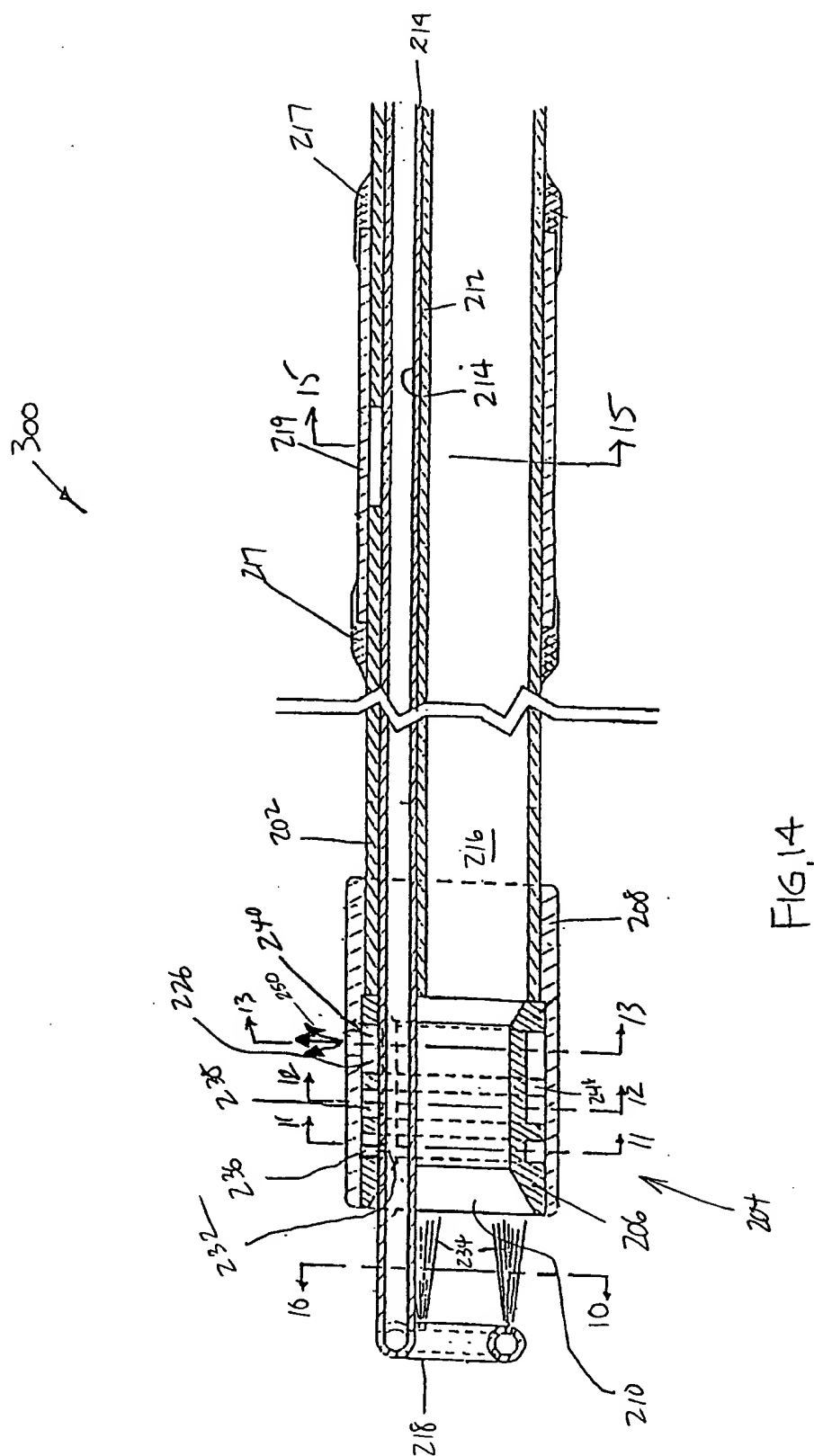


FIG. 13



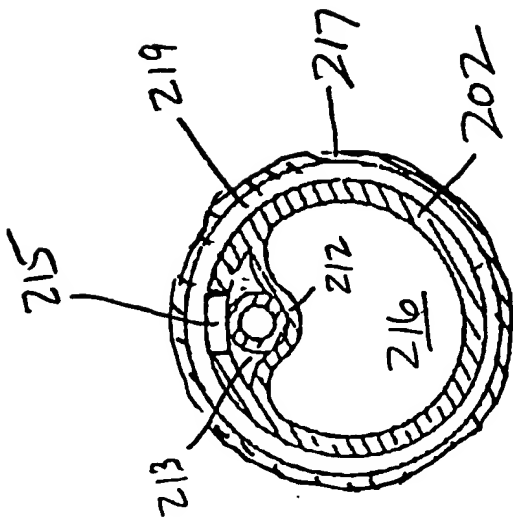
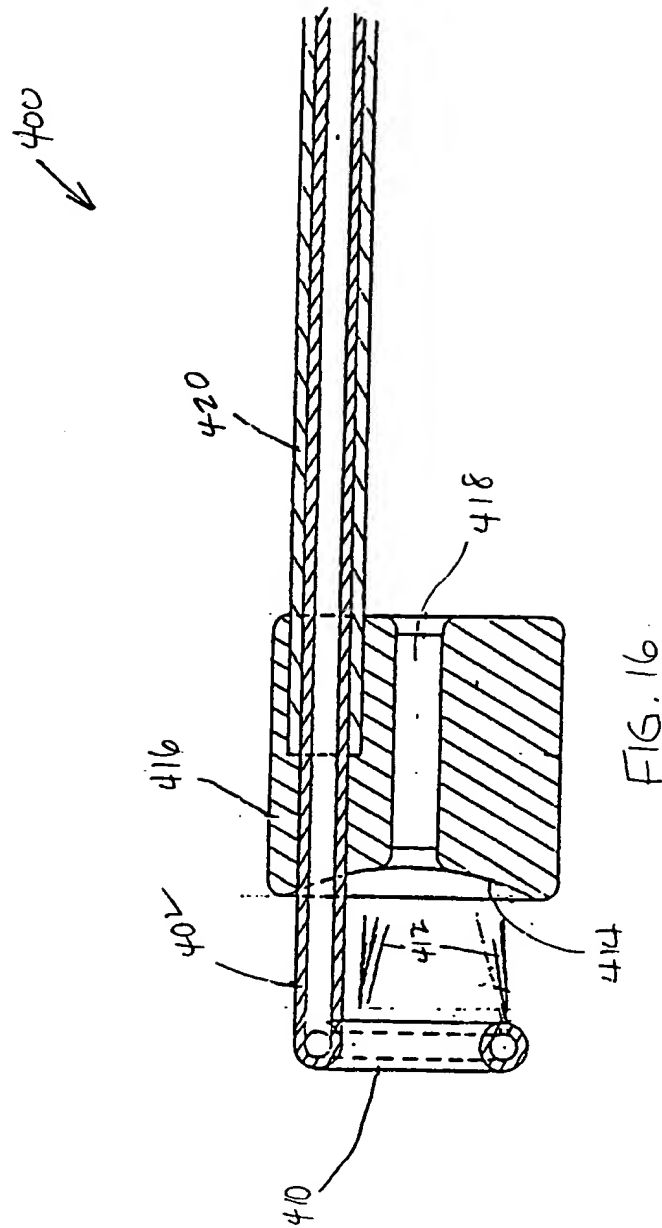
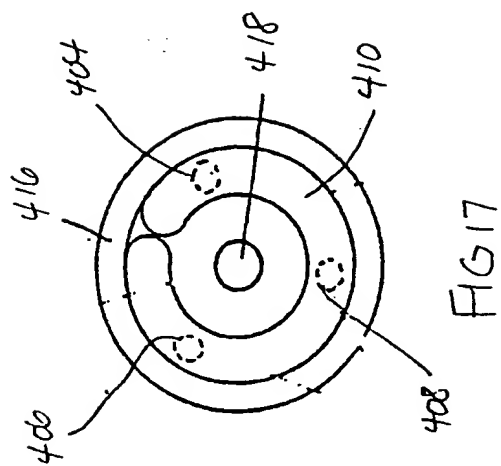


FIG. 15





INTERNATIONAL SEARCH REPORT

 International application No.
 PCT/US93/10735

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) : A61B 17/20

US CL : 604/22

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 604/22,35,43; 606/159,167,127,128

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

None

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

None

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A, 4,690,672, (Veltrup), 01 September 1987, Note Fig. 4.	1-7, 11-15, 19-25, 29-33
X	US, A, 4,790,813, (Kensey), 13 December 1988. Note Fig. 2.	1-2, 8-10, 19-20, 26-28
X	US, A, 4,950,238, (Sullivan), 21 August 1990. Note Figs. 1 and 2.	19-24, 26-31, 37, 39
X	US, A, 5,135,482, (Neracher), 04 August 1992. Note Figs. 3 and 9.	1-7, 11-13, 19-25, 29-31, 40-44, 48-52, 56-62, 66-68, 74-78

☐ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

01 FEBRUARY 1994

Date of mailing of the international search report

APR 15 1994

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